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August 30, 2013

Montgomery County Department of Permitting Services
25S Rockville Pike, Second Floor
Rockville, MD 208S0

Attn: Hadi Mansouri
Division Chief

RE: Westfield Montgomery Mall Westlake Garage
Gridlines 14 and 1S and C and D
Partial Precast Tee Collapse
Cause and Effect

Job No. 2013-10

Gentlemen:

I. Introduction

We were called on the evening of May 23, 2013 to assist in initial "emergency" make-safe operation and, after that effort, were retained to determine the cause and origin of the above-referenced construction incident, to determine the areas of the garage impacted by the construction incident, if any, and to design the final make-safe work needed to stabilize the garage structure impacted by the incident to a point where the original permitted work could continue to respond to the requests as outlined in your May 24 and June 20 letters to Messrs. Briggs, Peterson, White, and Draganov.

We also reviewed the exposed and visible portions of the full garage structure.

The procedures of the means and methods for the make-safe effort were designed by KCE, the specialty structural engineer for the make-safe work, and approved by RSA, the SEOR for the Project, per your June 20, 2013 letter.

The procedures of the means and methods for the make-safe effort were designed by KCE, the specialty structural engineer for the make-safe work, and approved by RSA, the SEOR for the Project, per your June 20, 2013 letter, and are documented on drawings EC-00 through EC-28, which were permitted under latest revision Permit No. 640290 (Exhibit 1).

We reserve the right to amend/modify this report when and if new or additional information is provided to us and/or new issues are uncovered in the future.

'I. Executive Summary

The Event was a tragic construction incident, which we believe resulted from the following sequence of events:

A "safety" tower wide flange header beam began to fail (twisted).

In an attempt to rectify the situation, WT re-jacked the tee up and was in the process of removing the slightly twisted steel section.

A jack/pump assembly may have malfunctioned.

The "jacking" tower scaffold legs were extended beyond manufacturer recommendations and extension sections were not braced per manufacturer requirements, which each reduced their load carrying capacity.

III. Immediate Efforts

We first visited the site at the request of Whiting-Turner (WT) on May 24 at 11:00 am and met with representatives of WT.

We noted the Urban Search and Rescue Team had installed emergency shoring as part of their rescue and recovery operation the previous day and had, as a part of that effort, moved existing shoring, pumps, etc. to install supports to limit further movement and for their access.

A precast, prestressed double tee approximately nine feet wide, sixty feet long, and twenty-six inches deep had fallen approximately eighteen inches, injuring two workers (one fatally).

The partially collapsed tee was a prefabricated, prestressed reinforced concrete element consisting of an integral flat top flange and downward projecting stems. The tees stems were supported by concrete haunches poured integral with precast concrete columns. The stems rested on neoprene pads on the haunches. The tees were connected to each other via intermittent weld plates (and welds) in the flanges. The top of each tee was encapsulated to the top of the column with a poured-in-place concrete wash poured into a dap (recess) in the flange.

Upon our arrival the partially collapsed tee exhibited a longitudinal crack in the Southeastern and Southwestern stem from the middle quarter toward the North. At WT's request and because the writer felt additional immediate shoring was required, we called Miller and Long DC, a concrete subcontractor that we have used for emergency shoring in numerous other accident situations, and had them install additional emergency shoring in locations selected by the writer.

IV. History

The precast, prestressed garage structure was designed and erected in 1975 by Shockey Precast Co., with spread footing foundations also designed by Shockey Precast Co. Charles H. Tompkins (now Turner

Construction) as the general contractor and Datum Inc. was the structural engineer (Exhibit 2). Over the years, various remediation work had been performed, the most recent in 2012, as designed by Desmond & Associates.

For reference purposes, the garage is divided into bays as follows:

- Bay 1 from gridline B to C
- Bay 2 from gridline C to D
- Bay 3 from gridline D to E
- Bay 4 from gridline E to F

Level 1 is the lowest level; Level Two is the next level above, flush with the grade entrance to the Food Court; and Levels 3 and 4 are above.

As part of the ongoing remodeling and addition to the Montgomery Mall, portions of the precast garage structure were to be removed and an additional theater element was to be built over the remaining garage and a food court expansion was to be constructed between the garage proper and the mall grade level commercial entrances (Project). The Structural Engineer of Record for the Project is Robert Silman Associates, PC (RSA) and the architect is Gensler.

Portions of the garage tees East and immediately West of the expansion joint on line 11/12 at Level 4 and East of the expansion joint were in the process of being removed by the demolition subcontractor, based on a design by their consulting engineer under a permit issued by Montgomery County Department of Permitting Services (DPS) (Permit No. 629764). The temporary shoring for that work was installed by WT (Exhibit 3).

In order to perform the multiple tee removals required, the standard procedure was to shore each tee to either side of the required centerline cut, remove the poured-in-place washes (and embedded chord conventional reinforcing), saw cut the tees in half (bay 3 was to be in thirds), the majority of which had not yet been cut at the time of the incident, saw cut the tee ends where required to free them from the columns, and lift the tee sections out with a Maxim® 500T Liebherr® crane positioned South of the garage structure.

The spandrel beam perimeter "walls" at the fourth level were then to be removed in a similar manner.

The East stair and elevator tower was also being demolished, but the South stair demolition had not yet started.

<u>Independent</u> of this operation, WT was in the process of relocating (via jacking) two tees on Level 3 (Level 4 had previously been removed over this area), each piece originally marked T-21 (the Shockey marking system called for multiple tees with same number) between column lines 14 and 15 and D and C. This tee relocation effort was the contractor's means and methods to provide a temporary opening in the precast garage deck through Levels 2 and 3 for the installation of a tower crane to be used to erect the new structure to be built over the partially remaining precast parking deck. The tees removed were planned to be reused and replaced after the tower crane was removed. The procedure used was not planned to be used elsewhere in the Project.

That tee relocation process was, following a design as shown on drawings J1-JS dated 5/15/13 and Procedure P1 and P2 dated 05/06/13 by WT (Exhibit 4) as follows: install shoring (two "safety" scaffold towers each end of the tee to be jacked) extending from the 3rd level to the foundation level and two "jacking" towers at each end of each tee "inbound" of the "safety" shoring towers. 10-ton minimum capacity jacks (20-ton jacks were used), two per tee end, were placed on the "jacking" towers (one on each tower) as described hereinafter. The poured-in-place wash was removed with a small hoe ram mounted on a Bobcat® and the end of the tee flanges and stems cut with a diamond saw short of the column haunches it had been supported by, to allow the tee to be jacked up. The "safety" shoring screw jack tower heads adjacent to columns were advanced upwards by turning the screw jacks on the scaffold as the jacking operation advanced. Once the tee being jacked was above the adjacent floor level, using "rail" beams to support the tee, it was to be pulled (skated) with a Lull® (a Bobcat-type machine) and was to be pulled up the ramp and placed on cribbing with one floor of shoring below when the incident occurred up the ramp to a location two tees away. (The third floor tee was already removed at the time of the incident.)

One tee (T21) at the third level (the Easternmost) had been relocated (skated) via the procedure described above.

The second tee (another mark T21 West of column line 14.3-14.7) was in the process of being jacked.

Structural steel assemblies were installed in the head (top) of the "safety" tower and "jacking" tower sections. Those head sections consisted of rolled wide flange structural steel shapes of A572 steel (50 ksi yield strength). The structural steel was purchased by WT from D.S Pipe and Steel Supply, Inc. and fabricated on site.

The "jacking" and "safety" shoring towers (SAFWAY®) were leased from Scaffold Resources by WT and were erected with 6" wide flange beam bases supporting two sets of tower legs following the ±5% garage ramp slope. Those beams connected to the tower legs with C clamps.

Four jacks and pump assemblies were leased from Zenmar Pneumatic Tools, Inc. by WT, with one jack placed under each stem of the Southern tee ends, and one each under the two Northern tee stems, each with its own individual pump assembly, placed on the "jacking" tower(s).

(We would note the garage design documents used a column grid nomenclature repeated on the Project with a 'P' preface while the grids used for the mall remodeling work are a different numbering system.)

The writer has had informal individual interviews with seven of the workers and the foreman who were performing the jacking/tee relocation work, which yielded the following information:

- They turned the screw jacks at the top of the "safety" tower by hand to keep them snug at all times.
- They operated the jacks in unison on verbal command from the foreman.
- The second tee to be relocated (the failed tee) was in the process of being raised.
- They were having issues with a jack – it required more strokes to get the lift to follow the other jacks' progress.
- The tee was level ± ½".

- Just came back from break (left tee in place supported by "safety" towers, with jacks released) and noted a partially buckled web and slightly twisted flange (partially buckled) of the wide flange section supporting the tee at Southeast corner and were attempting to rejack that corner to remove and replace the deformed wide flange.
- An equipment operator was bringing a crescent wrench to the ironworker who died.
- All heard a loud cracking noise (the injured worker heard what he described as a loud boom), then metal noises.
- They then (after the partial collapse) saw long diagonal cracks through the Southern tee stems of the tee being jacked.
- After the Event, they grabbed a ladder to allow the man whose arm was trapped to be supported and moved scaffolding and other items in order to place the ladder and to try to get to the other man.

An ironworker was positioned at each jack location and one other ironworker was positioned on each of the "safety" towers. There was a foreman on the deck. The men, in an orchestrated procedure, as directed by the foreman (who stood in the middle of the bay), attempted to jack (lift) the tee upward (i.e., following the slope of the deck a 5% ramp) as uniformly as possible. A laser level was used to indicate the levelness. The jacking process required multiple jack reinstallations due to the maximum useable stroke on the jacks, their 12¾" retracted height, and $20^{7}/_{8}$" extended height to get the tee stems above the adjacent remaining tees. As the jacks advanced and the tee moved upward, the men at each end would raise the "safety" tower heads so the tee would always be supported by the "safety" towers. When the jack reached maximum available stroke, one of the men at each end would clamp the "safety" tower head wide flange beam to the tower screw head saddle, another would lower the jack and remove it, install a steel wide flange spacer section or raise the tower, and then reinstall the jack. Wood blocking was used where required to shim the tee.

That tee was in the midst of being jacked up with the North end above the level of the remaining uphill slope tee that was to remain, but the south end not yet clear of the adjacent tee.

Immediately preceding the incident, the men verified the tee was supported by the "safety" towers and went on break.

When they returned, they noticed a "safety" tower head W8 had partially buckled (top flange and web were bent ±¼" to ½") and determined they should replace that piece of steel – the correct thing to do.

They began pumping the jack again to get the load off of the partially buckled beam.

One of the workers (the one injured) reached in to get the deformed beam (he indicated it was ± ¼" to ½" "clear") and pull it out to replace it with another section (he advised the piece was free at the time). There was a loud noise and the tee fell (±18", pinning his arm. As the tee twisted and fell, the other stem hitting his partner and killed him.

We believe his partner may have asked for the crescent wrench to tighten the safety tower clamps.

(The tee profile, as collapsed after the Event on our first visit, indicated the leading edge (i.e., the Southeast corner) of the tee was being jacked.)

f. Emergency Work Performed at Our Direction

- Additional shoring was installed by Miller and Long at our direction in the areas immediately adjacent to and under the collapsed third level area, which had been additionally shored by the Urban Rescue Team between column lines 14 and 1S and C and D, as well as under the second level between column lines 14 and 16 and C and E, including installing header beams in the head of the four crane leg sections that had been erected under the second level.

- VIKA LLC performed a 3D scan of bays 14 to 16 and C to E at levels 4, 3, and 2 (Exhibit S).
    - Monitored area for movement on a daily basis

- "Debris" pieces were marked by KCE individually with a numeric code (Exhibit 6).

- Detailed photographs were taken by KCE of the debris area and adjacent bays. See photographs 1122-1162, 168-1729, 1736, 1737, 1746-1792, and 1801-181S (Exhibit 7).

- We inspected the balance of the exposed and visible structure of the precast Westlake garage. Several areas of insufficient tee bearing (based on the original Shockey documents) were noted, as well as five tee stems with longitudinal cracks. (We had those shored.) It is our professional opinion that these bearing situations and cracks were not related to this incident. Desman was engaged to address these items.

- The area between column lines 13 and 16 and C and D was fenced with one gate for access at each end with security key access only for WT, VIKA, KCE, and the Montgomery County Department of Permitting Services and/or their representative.

- We collected various drawings and specifications, including, but not limited to:
    - The original Woodward and Lothrop architectural and structural drawings dated April-October 1972 by Ralph Kellman
    - The original Shockey Brothers drawings dated April-July 197S
    - Desmond garage repair drawings circa 2007, 2009, 2011, 2012
    - Gensler general interior demolition drawings dated 3/26/13
    - Silman structural drawings Addendum 4 dated 3/26/13 for the new structure (and later a complete set)
    - Silman drawing indicating tee removal areas and purpose
    - Demolition drawings 4th floor tee removal
    - Third-party inspection reports
        - Soils
        - Concrete cylinder reports
    - WT prepared jacking procedure documents

- We met with you and your staff. A process was developed for the make-safe work, with KCE as the Specialty Engineer of Record and RSA remaining as Engineer of Record for the entire Project approving all make-safe work as well as this report.

'I. **Structural Make Safe**

Procedures of Means and Methods of Make-Safe (Under Our Observation)

The procedures of the means and methods for the make-safe effort were designed by KCE, the specialty structural engineer for the make-safe work, and approved by R5A, the 5EOR for the Project, per your June 20, 2013 letter.

In summary, we designed the following structural make-safe work, shown on EC-00 through EC-28 dated 6/27/13 and permitted under Permit No. 640290 dated 7/1/13 with revisions as noted herein, which included the work required, e.g.:

Erection of Waco high load 25 kip per leg shoring from ground level to the 2^{nd} floor in bay 1 from column line 17 to 11/12 to provide additional lateral stability and a safe means of emergency egress from the lower level theater and to allow continued removal of the 4^{th} floor tees per the original demolition permit.

Installation of additional shoring in the collapse zone under all levels to foundation.

Hazardous material removal.

Relocation of tools, jacks, original scaffolds, jacks, and wide flanges to a new onsite fenced and locked storage area.

Removal of pumps, jacks, and selected scaffold sections (portions cut to facilitate removal) other than those still touching the tee, from the fenced onsite secure storage facility noted above, which were shipped and tested per the attached protocols (Exhibit 8).

Completion of the sheeting, shoring, tieback, and wale installation.

Completion of the removal of fourth floor tees that had previously been cut in half and shored per the previously issued demolition permit and then removal via the original permitted demolition plan for fourth floor tee removal. KCE requested some modification, e.g., strapping (utilizing the Maxim® 500T crane already on site) after the permitted sheeting and shoring work on the 5outh side of the garage was completed.

Another crane (the North crane) was brought in to facilitate the tee removal work (see EC series drawings).

<u>Failed and Skated Tee Removal</u>

In order to safely remove the partially collapsed tee and the skated tee, four additional tees at Level 4 over the partially collapsed tee and two over the skated tee had to be removed. The process for that effort was to install three/four rows (in plan) of 25 kip Waco shoring towers extending to grade and supported on new temporary concrete foundations, hand chip the existing poured-in-place wash at the tee, core drill two rows of ±4" diameter holes through the flange of tee outboard of the stems, saw cut the ends of the tees vertically to free them, place a

high capacity set of slings with softeners, looped through the cored holes, under and around the two stems, and remove the tee sections with the South crane.

After the removal of additional tees on level 4 as noted above, a Brokk® 330 remote-controlled device with a muncher head was lowered onto 6" structural Styrofoam with ¾" plywood sheathing on the second level tee adjacent to the partially collapsed tee with Waco shoring in that bay to grade. Steel girders were installed, resting on wood cribbing with lateral Burke braces on the downhill (East) side on the fourth floor deck over the newly created opening below. Using high-capacity beam clamps and chain falls, high load slings were placed under and around the partially collapsed tee stems and snugged up. The Brokk® remote-controlled machine was used to munch the partially collapsed tee section. The same softening material was placed (where safe access was available) under the partially collapsed tee as a shock absorber at the catch level for debris.

The munched debris (concrete and prestress wire) was collected, removed, and placed in a dumpster placed in a portion of the Sears' parking lot. Pieces of that debris were removed directly from the debris field and were shipped for testing to American Petrographic Services (concrete) and Metallurgical Technologies (metal).

The previously skated tee was then removed per the two-piece removal scheme noted herein.

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VII. Materials and Equipment Testing

A. Pumps (Tested by VSL (Struc'tur'al Technologies – Exhibit 9)

SUMMARY

Pump Cylinders - All BVA Hydraulics® *25 ton, 8" strake,* *10,000 psi mox*	***Hand Pump***	***Gauge***	***Hose***
K408 *Missing jocking soddle*	*Enerpoc®* *Unstoble stand* *Release volve bent* *Oil low*	*Enerpoc® GA-3* *700 Bor** *Pump pressure issues*	*Enerpoc®* *10,000 psi*
K681 *Missing soddle*	*SPX Power Teom®*	*Power Teom®* *1034 Bor* *Pump pressure issues*	*Enerpoc®* *10,000 psl*
K629 *Cylinder retractor jerky*	*SPX Power Teom®*	*Enerpac® GA-3* *700 Bor* *Minor oil leak at threads* *Pump pressure issues*	*Enerpoc®* *10,000 psi* *Kinked ond damoged* *Leoking*
K409 *Cylinder does not retroct fully ond when pushed to 0 extends ogoin under no pump pressure*	*Enerpac®* *Overfilled pump with residuol pressure*	*Enerpoc®* *700 Bor* *Pump pressure issues*	*Enerpoc®* *10,000 psi*

*Bar is a unit af gauge pressure. 1 bar is approximately 14.5 psi; 700 bar is approximately 10,000 psi

- *Missing lifting soddles* means that those jacks were not of the same gross height as the others and overall length varies from other jack (i.e., not 0).
- *Two of the gouges did not reod the correct pressure (i.e., octuol pressure vs. gauge pressure reod 500 to 1000 psi higher).*
- *One pump wos overfilled with oil ond had residuol pressure in reservoir tonk (3" rom extensions with na pressure)*
- *The effort required to odvance the rom cylinder under higher pressure voried between pumps (Power Team® wos duol stoge; Enerpac® unknown).*
- Leaking oil intra-chambers - *there wos a slow ail leak from the fill port.*
- *One hose wos bodly domoged.*

The condition of the pumps, which the ironworkers may nat have known in detail, indicated one jack may nat have been able to hold load; however, no oil stains were nated in the debris field and the damage cauld have occurred as part of the incident or the aftermath.

B. Scaffold – Materials Testing by Metallurgical Technologies – Summary (Exhibit 10a)

Scaffold tower sections met ASTM A500 material qualifications, sans the shoe clamp af ane tawer. The threaded stems, tawer legs, and braces were of different steel grade.

The bracing connection nubs that bent or broke off failed in brittle failure mode under load (Exhibit 10b).

The nub strength requirements are not known; one had lower tensile value than the others.

The steel rolled wide flange section met material standards of ASTM A572.

The "bridge" clamps showed no evidence of brittle failure. Their tensile strength varied.

The partially buckled beam section sample # CCFK14A (KCE #410) was too short to be tested for tensile strength but based on materials evaluation showed nothing "out of the ordinary."

Prestressing wire was tested and was found to be 288 ksi in excess of that required per the original drawings.

C. Concrete Sample Testing by American Petrographics – Summary (Exhibit 11)

Three cores taken from the partially collapsed tee (after munching) were tested for concrete strength and were viewed petrographically. The concrete met the acceptability requirements of ACI 318.

VIII. Construction Shoring Procedure For Tees to Be Jacked

The shoring towers were to be installed in accordance with Whiting-Turner drawings J1-J5 dated 05/05/13 and written procedure P1 and P2 dated 05/06/13 (Exhibit 4). Each double tee one tee West of gridline 14 to one tee South of gridline 15.4 would have 2 "safety" towers per end (highlighted in blue in Figure 1) and the tee being jacked would have 2 "jacking" towers per end (highlighted in green in Figure 1). At the time of the collapse the double tee west of gridline 15 had been jacked and skated over to its temporary stored location. The partially collapsed tee was located mid-bay between gridlines 14 and 15.

"Safety" and "jacking" towers on the North end of the double tee remained in place (one was fallen over) while the "jacking" and "safety" shoring towers on the South end were partially collapsed and deformed and some had been displaced by the workers when attempting to assist their trapped men and by the emergency rescue team.

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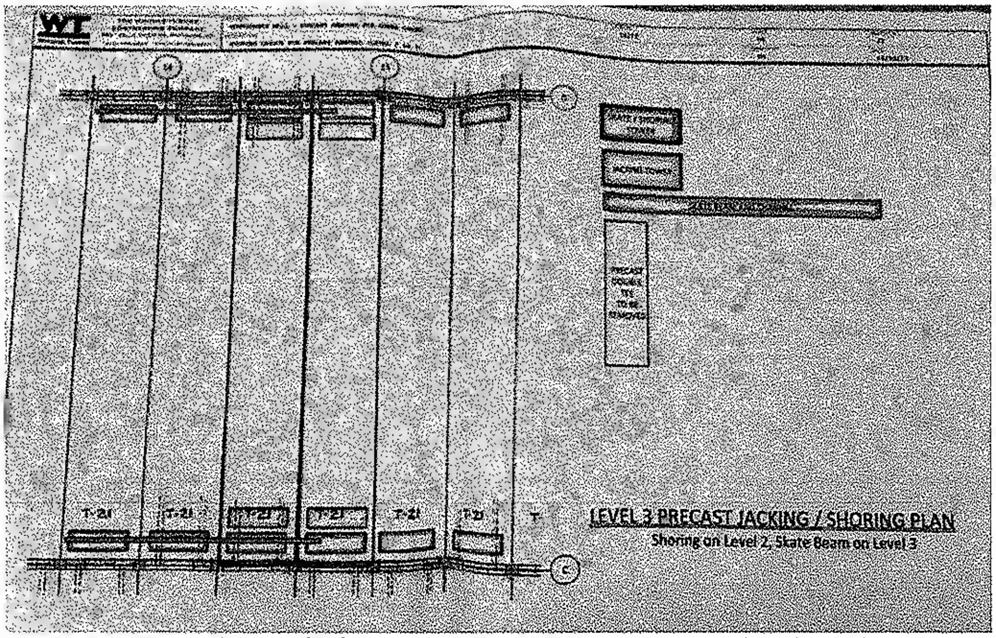

Figure 1 - WT Drawing Sheet J2 dated 05/05/13: Shoring Layout for Precast Removal (Level 2 to 3)

The WT Shoring/Jacking/Skating Procedure documents state the double tee was to be jacked 6" per increment using jacks supported on "jacking" towers in the configuration shown in Detail A on sheet J3 (exhibited in Figure 2 below). The towers rested on W6 runners directly on the Level 2 deck. The "safety" tower heads were raised as the jacking process proceeded to continuously support the load of the double tee. The jacks were then to be released to allow the precast load to "settle" on the "safety" shoring towers, the "jacking" towers' elevation adjusted, the jack reinstalled, and the steps repeated until the precast double tee was high enough to slide the tee over the adjacent double tees, which were to remain, to its temporary location.

The transverse W8x31's were placed snug to the bottom of the stem of the double tee and the double tee was jacked from the longitudinal W8x31 Jacking beam, shown in orange.

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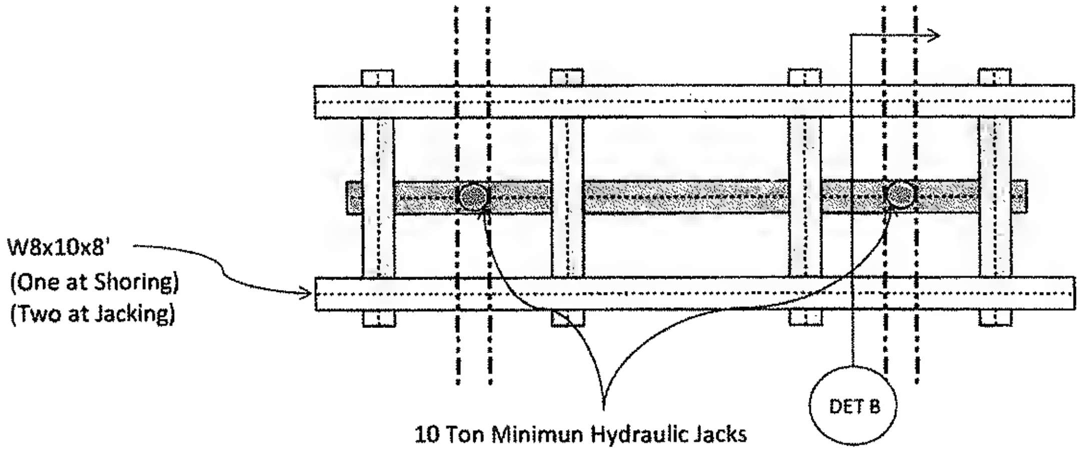
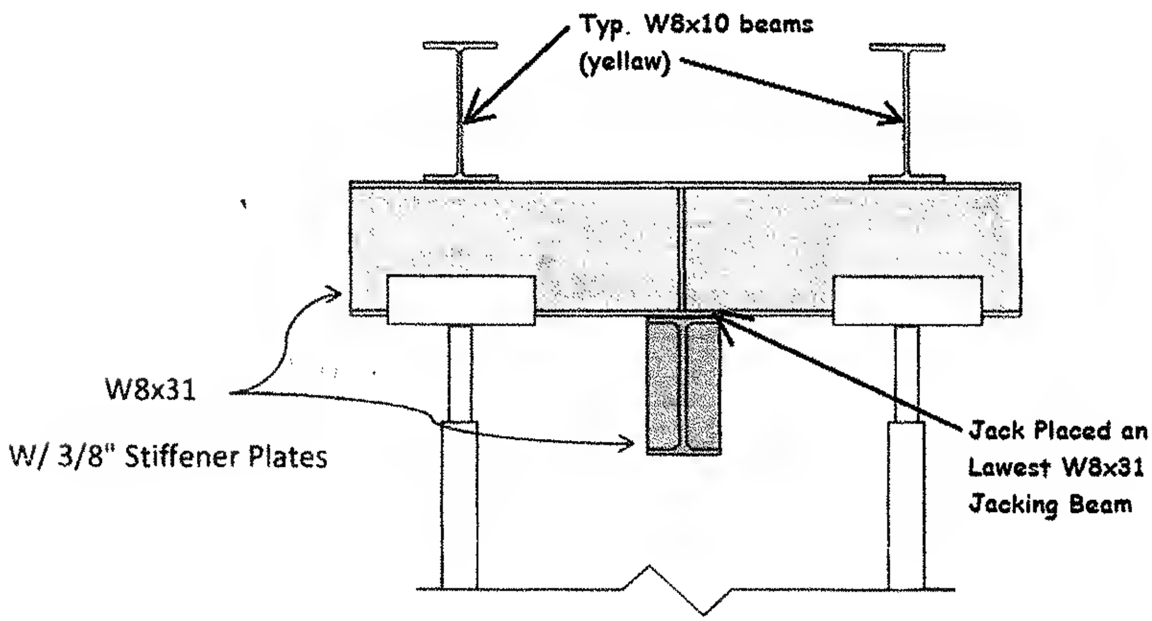


DETAIL A - JACKING TOWER RIG DETAIL

Figure 2 - WT Drawing Sheet J3 dated 05-05-13: "Jacking" Tower Configuration (Color added by KCE.)



DETAIL B - JACKING FRAME SECTION

Figure 3 - WT Drawing Sheet J3 dated 05-05-13: Section of "Jacking" Tower Configuration (Notes in bold and color added by KCE)

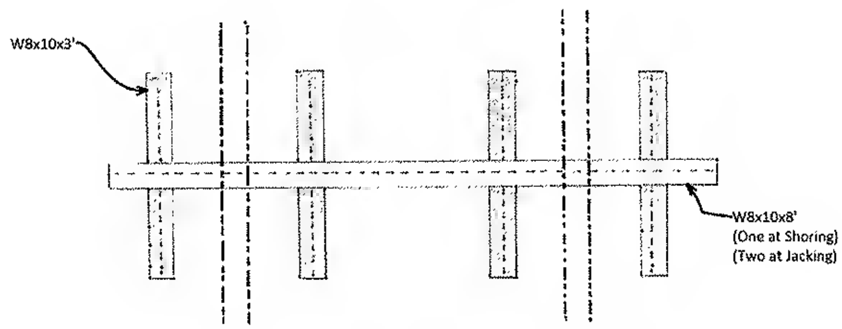


Figure 4 - Plan view of "Safety" Tower Configuration
(Sketch by KCE.)

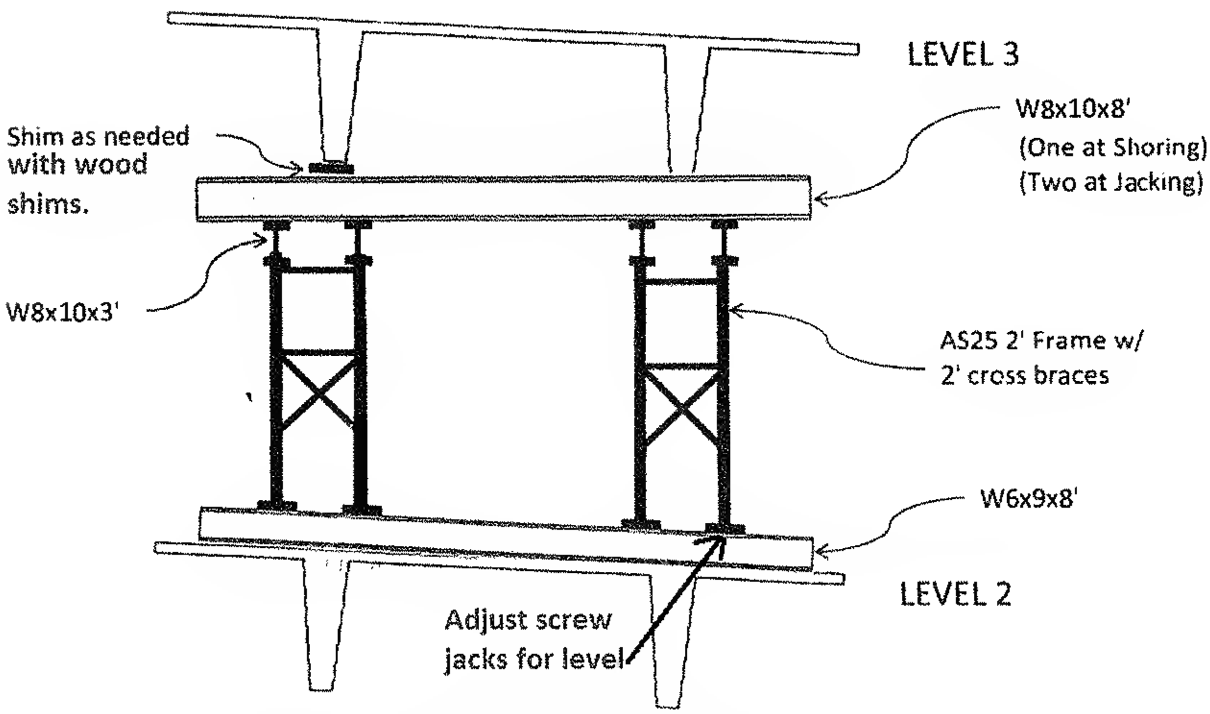


Figure 5 - WT Drawing Sheet J3 dated 05-05-13: Section of Safety Tower Configuration
(Notes in blue and color added by KCE.)

For our analysis, the weight of an individual double tee was taken to be 43,992 pounds, taken from piece mark T21 detail S on sheet 5.B.-5288-F by Shockey dated 7/02/75.

For clarification purposes, the steel beams spanning perpendicular to the stems of the double tee are referred to herein as longitudinal (East to West) and beams running parallel to the stems of the double tee are referred to herein as transverse (North to South). Both longitudinal and transverse beams on the "safety" shoring tower were to consist of W8x10 beams. The "jacking" tower configuration was to consist of W8x31 transverse beams and was to include a continuous W8x31

jacking beam below the transverse beams and two W8x10 longitudinal beams on top of the transverse W8x31's.

As shown in Figure 2, there is one jack per stem of the double tee at each end, for a total of four jacks. Given that there were four separate jacks with four different operators running them, and the "jacking" towers were on a ±5% slope (following the ramp) and plumbed with the "safety" jack leg to make the tower plumb, it is possible that the double tee may have been jacked somewhat unevenly. Jacking the tee unevenly could produce unequal load distribution, inducing lateral forces into the "jacking" shoring towers. (SAFWAY® does indicate the lateral load carrying capacity of their scaffold.)

A. Base Shoring Tower Leg Capacity:

WT drawing J3 specifies AS2S 2' frame base section with 2' cross braces to be used between levels 2 & 3. AS25 frames are a part of the SAFWAY Adjust-A-Shore® shoring system. According to the AS2S base frame specification sheet by SAFWAY®, the maximum rated load is 11,000 pounds per leg. This maximum rated load is based on a maximum screw jack extension ≤12" and includes a 2.5:1 factor of "safety". When the screw jacks are extended past 12" to a maximum allowed extension of 20" the maximum rated load is to be reduced 5% per inch beyond 12" of screw jack extension. Therefore if the screw jacks were fully extended to the 20"extension the maximum rated carrying load is reduced from 11,000lbs to 6,600 pounds. We measured maximum 16" extensions, which yields a maximum rated carrying load of 8,800 pounds and a failure load of 22,000 pounds.

B. Base "Safety"/"Jacking" Tower Load Distribution VS. Failure Load:

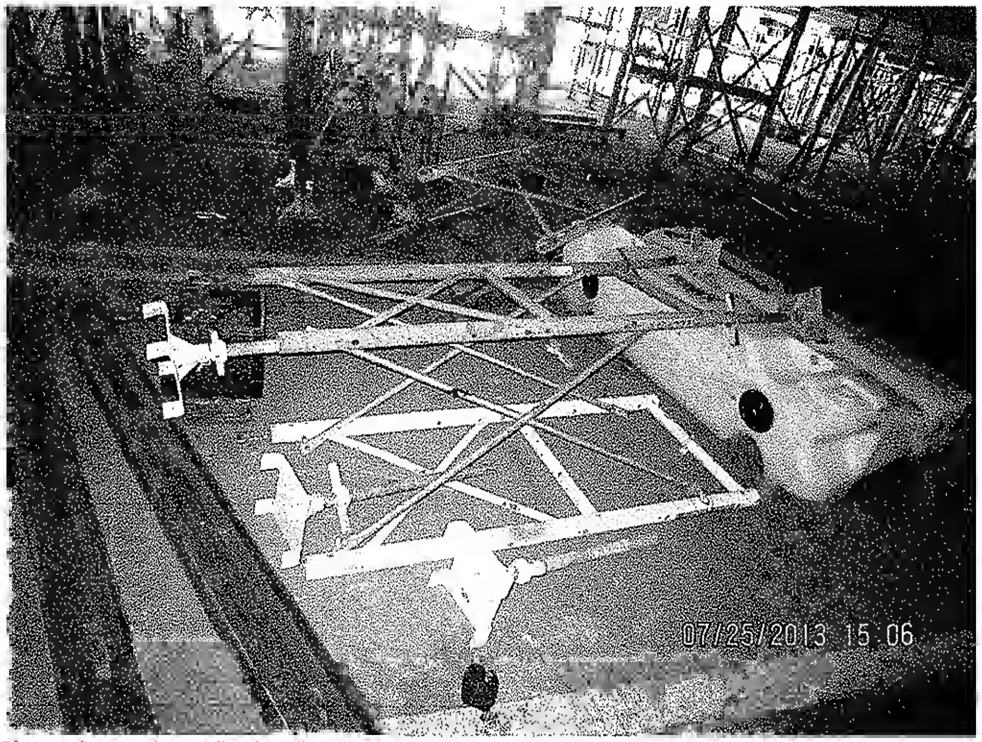
According to the WT drawings, a typical "jacking" tower consisted of two 2'x2' AS2S Adjust-A-Shore framing towers set up as shown Figures 2 and 3 above. The weight of the precast double tee would therefore be transferred to a longitudinal W8x10 spanning across four transverse W8x10's. The transverse W8x10's were supported by the AS2S Adjust-A-Shore framing towers.

As can be seen in Pictures 1-3 below, the screw jacks were extended beyond 12" therefore reducing the capacity of the shoring towers. The extension shown in Picture 3 was measured to be a minimum of 16".

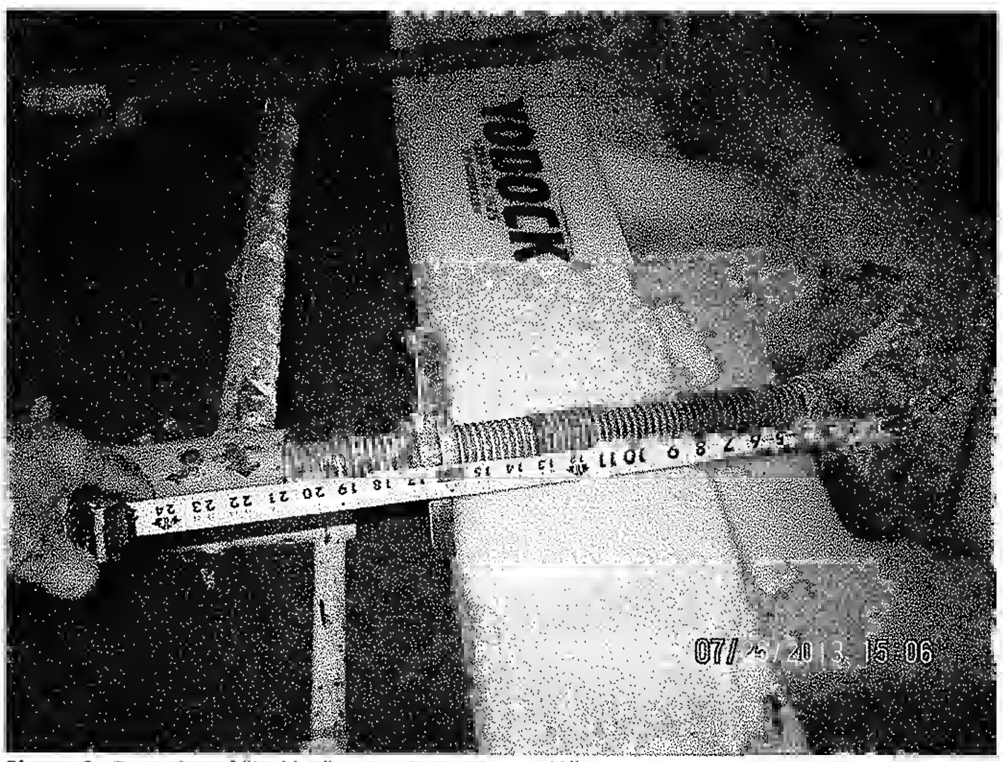
Assuming a worst case scenario with the entire load of the double tee transferred to one jack, the maximum reaction to the transverse W8x31 beams would be 30,000 pounds (30 kips).

If 30 kips were applied to the transverse W8x31 directly in the center of the beam, distributing the load equally to each leg of the shoring tower, the reaction per leg of the frame would be 15 kips. The failure load of the AS2S base frame is 22 kips if the screw jacks are extended 16". Therefore, this scenario alone should not result in failure of the tower.

The "jacking" tower arrangement is configured so the longitudinal (low) W8x31 beam is bolted to the transverse W8x31's beams, securing its location. It is not likely that the load being applied to the transverse beams would be eccentric. Therefore, for our evaluation, we used a load on the transverse W8x31s equally distributed to the supporting legs of the AS2S base frames.



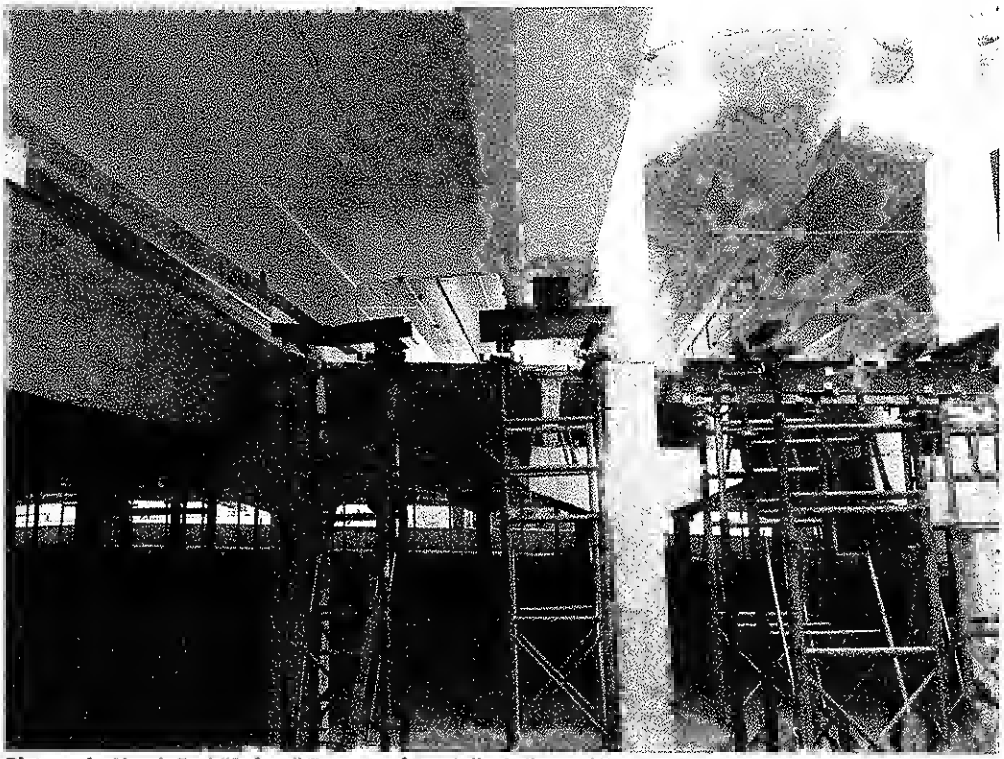
Picture 2 - North End "Jacking" Tower



Picture 3 - Extension of "Jacking" Tower Frame Base > 12"

Based on the site photographs we took upon arrival, the as-designed shoring tower layout may not have been adhered to throughout. As can be seen in Picture 4 two smaller individual W8x10

beams are spanning the shoring towers in the longitudinal direction as opposed to the continuous 8' W8x10 spanning both 2'x2' Adjust-A-Shore® framing towers as shown on WT drawings J1-J5.



Picture 4 - North End "Safety" Towers of Partially Collapsed Tee

The "safety" towers under the partially collapsed tee were not installed per WT sheets J1-J5 dated 05/05/13 or sheets P1 and P2 dated 05/06/13. The continuous W8x31 jacking beam was not placed spanning the two "jacking" towers but rather two separate beams were used. (Having two separate longitudinal beams allows each individual 2'x2' A525 Adjust-A-Shore shoring tower to be moved and placed independently of each other and extended to different heights for construction adjustment.)

C. Capacity of Beams:

In the configuration shown on WT drawings J1-J5 the W8x10 and W8x31 beams on the "safety" and "jacking" towers have adequate strength to support the load of the precast double tee even if the entire load is concentrated in one location on the beam. This is true as long as the load is applied to the strong axis (Figure 6). As can be seen in Picture 4, where the longitudinal beam rotated, apparently during the collapse, bending will occur when load is applied to the weak axis (Figure 6).

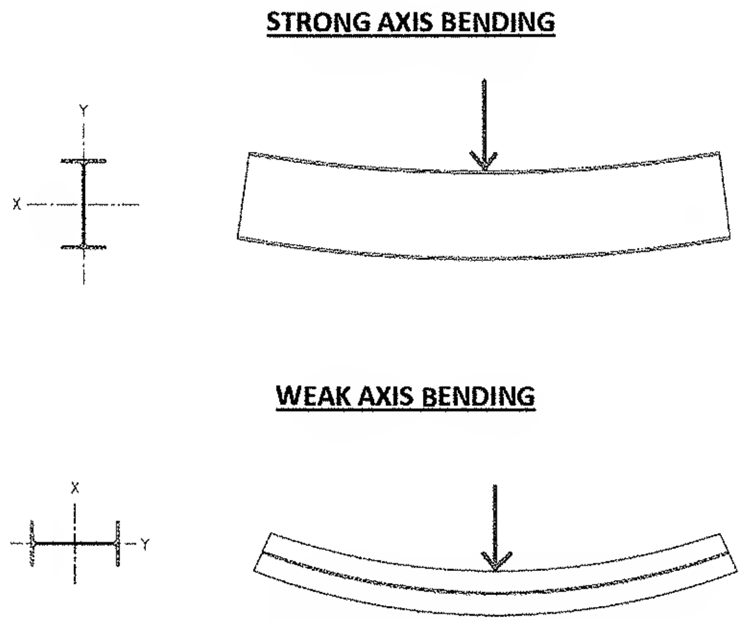


Figure 6- Diagram of Strong and Weak Axis Beam Bending

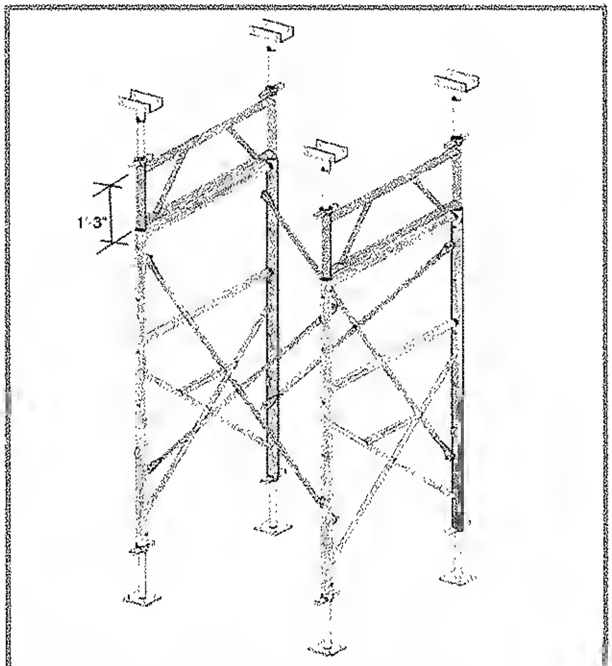
D. Web Compression Buckling

Web compression buckling occurs when a beam experiences a load or reaction at the top and/or bottom of the beam. It appears that the workmen placed short pieces of wide flanges (not per the WT drawings) between the longitudinal W8x10s and the double tee stems. The short pieces of wide flanges experienced a compressive load from the weight of the double tee as well as the reaction from the beam below. These loads caused compression in the web. When the capacity of the web is exceeded, the web buckles. If the double tee was jacked and consequently supported unevenly, the weight of the double tee would not be distributed evenly. It is possible that enough load could be imposed on one of these beams to cause web compression buckling. This "failure" mode is evidenced in multiple pieces of beam in the debris field. (The buckling (i.e., crimping) is what was noted by the iron workers on the one beam that they then were attempting to replace.)

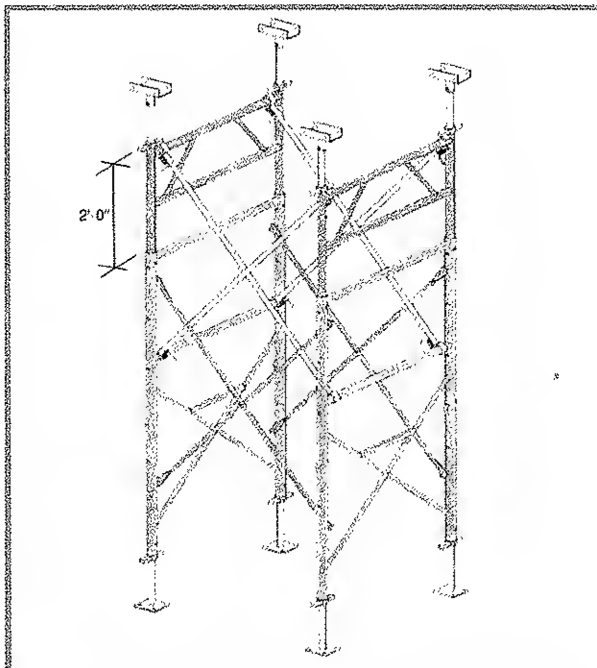
E. Connections

The transverse W8x31 beams of the "jacking" towers were resting in the U-head on top of the screw jack of the shoring tower. The longitudinal W8x31 Jacking beam was connected to the transverse W8x31 beams with a bolted connection. The longitudinal W8x10's on top of the "jacking" tower were set loose in the head.

The transverse W8x10's of the "safety" towers were supported in the U-head on top of the screw jack of the shoring tower with C clamps on some, but not all, heads. The longitudinal W8x10 was resting loose across the transverse W8x10's.



Base with 1'-3" Extension taken from SAFWAY Adjust-A-Shore® Product Selection Guide



Base with 2'-0" Extension taken from SAFWAY Adjust-A-Shore® Product Selection Guide

Figure 7 - SAFWAY Bracing Configurations for Extended Frames (colors added by KCE)

F. AS24 Extension Frames:

Extension frames (AS24) were installed in the base tower to achieve the necessary height in the towers with some 2'-0" extension.

The SAFWAY Adjust-A-Shore® Product Selection Guide notes that AS24 extension frames can be used to extend the height of AS2S Base Frames. When the height of extension is 2' or greater additional diagonal gooser (cross) braces are needed (See Figure 7 above, which indicates the configuration of a 2' extension with the required gooser braces (shown in yellow)). It also indicates the configuration for a 1'-3" extension when no additional bracing is required. The towers on site have the AS24 extension frames. Additional extension of the "jacking" towers was accomplished with the screw jack extensions. The "safety" towers did, however, utilize the AS24 extension frames with a 2'-0 extension but no gooser bracing was installed.

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Picture 5 - Shoring Tower with Extension and no additional bracing

G. Lateral Movement:

Whenever a load is applied at an angle to an element, the load is resolved into a vertical force and a horizontal force. If the tee was being jacked unevenly, it resulted in the tee being at an angle in the North-South direction, and, due to the ramp slope, in the East-West direction, a horizontal force would be introduced to the shoring towers. Without the bracing in the extension frames and no lateral bracing between the towers, additional movement is likely to occur and more force is likely to be introduced into the intra-tower cross bracing. It can be seen in many locations that the connection pins for the braces were in fact sheared and/or bent (Picture 6). The cross bracing buckled and the base tower legs split at the interface with the male extension section inside the female base tower leg.

[Balance of page intentionally left blank.]

Picture 6 - Connection pin of base frame

IX. Summary

We would note the actual location of all of the shoring towers, jacks, etc. immediately after the failure is not precisely known due to the initial efforts of the workers to "support" the trapped man and the need by rescue personnel to clear the area in order to get the trapped workers out.

The jacking was proceeding with the tees nominally level.

The jacking operation was proceeding with some jack/pump performance issues, the cause of which we believe the ironworkers may not have known about.

The towers supporting the jacks may not have been centered under the tee stems and therefore the jacks may not have been centered on the beams.

The scaffold towers were erected without all of the necessary intra-tower cross bracing, in the extensions and the base sections themselves and had screw jack leg extensions that lowered the load-carrying capacity of the composite towers.

When the Southeastern jack was raised to replace the partially deformed wide flange in the "safety" tower, the jack, the support framing, or the scaffold failed.

X. Conclusion

Based on our review of the exposed and visible conditions, of the balance of the garage structure, there was no detrimental effect to the remaining garage structure due to this incident. This Cause and Effect report does not undertake a review of the remaining garage not impacted by the Event.

We believe we have responded to the requests noted in your May 24, 2013 and June 20, 2013 letters, namely: (Note: your requests are italicized and comments we added are "regular" text. Emphasis (bold/underlining) is per your letters.):

<u>May 24</u>

a. *A report describing the existing conditions of the garage where work was taking place;*
b. *The means and methods employed in the carrying out of the work;*
c. *The specific cause(s) of the collapse;*
d. *Means and methods of construction for remedial actions needed due to the Event for work to proceed;*
e. *An indication of the proper procedure to remove double tees from the garage relative to placement onto the deck and the capacity of the remaining double tees to support such additional loads.*

<u>June 20</u>

a. ***First**, a site stabilization plan* [has been] *provided by the SER immediately with construction means and methods <u>approved</u> by the SER which will allow for the garage to be secured and stabilized to a point where in progress work can be safely completed and a moveable crane can be positioned so that precast elements can be removed and demolition work can resume as described below <u>(the "Stabilization" Plan)</u>.* NB: this was, per our meetings, modifications to the plan drawings and certified by the specialty engineer and approved by the SEOR.
b. ***Second**, a forensic analysis report* [has been] *prepared by, or be reviewed and approved by, the SER as directed in [your] May 24, 2013 letter (the "Forensic Report").*
c. ***Third**, a Repair Plan that provides for a safe and stable construction environment* [has been] *developed by the SER and submitted to DPS approval under a new permit that provides for the stabilization of the garage for construction work to resume.*

If we can be of further service, please contact this office.

Very truly yours,

Allyn E. Kilsheimer, PE
President
KCE Structural Engineers, PC

STATE OF MARYLAND
ALLYN ERIC KILSHEIMER
No. 6774
REGISTERED
PROFESSIONAL ENGINEER

AEK:ms

Professional Certification. I hereby certify that these documents were prepared or approved by me, and that I am a duly licensed professional engineer under the laws of the State of Maryland.
License No. 6774 Expiration Date: 12-30-2013

We concur with the findings and conclusions of the report.
ROBERT SILMAN ASSOCIATES

Tom A. McLaughlin, P.E.
08/30/2013

Cc: Scott Titmas/Westfield, LLC
Chris Hoyson/Whiting-Turner Contracting Co.
Tom McLaughlin/Robert Silman Associates